Issued January 11, 1908.

U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN 315.

PROGRESS IN LEGUME INOCULATION.

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WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1908.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., December 4, 1907.

Sir: I have the honor to transmit herewith a paper entitled "Progress in Legume Inoculation" and to recommend that it be published as a Farmers' Bulletin. This paper was prepared by Mr. Karl F. Kellerman, Physiologist in Charge of Soil Bacteriology and Water Purification Investigations, and Mr. T. R. Robinson, Assistant Physiologist.

Although this paper contains considerable new material, it is practically a revision of Farmers' Bulletin No. 240 and is intended to supersede it for general distribution.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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PROGRESS IN LEGUME INOCULATION.

INTRODUCTION.

The peculiar value of legumes for maintaining and increasing the fertility of soils is due to certain bacteria which develop nodules upon the roots of leguminous plants and which have the unique power of rendering the free nitrogen of the atmosphere available for plant growth. Without these bacteria, legumes, like other crops, exhaust the soil of its combined nitrogen. In many regions certain types of these important bacteria are abundant in the soil; in other localities they must be imported, either by distributing soil from a field where they are known to be present or by using pure cultures of the proper organisms grown under artificial conditions. The old method of importing the bacteria by distributing soil from fields containing them is not only expensive but there is very great danger of spreading weeds and destructive crop diseases as well as the desirable bacteria. Under modern conditions, therefore, it is wisest to depend chiefly upon the intelligent manipulation of pure cultures for inoculating leguminous crops.

THE USE OF PURE CULTURES OF NITROGEN-GATHERING BACTERIA.

Recent improvements in the methods of preparing and distributing pure cultures for inoculating leguminous crops have obviated many of the difficulties previously experienced in their use. The directions for handling by the planter have been simplified and adaptations have been made to meet varying conditions of field and plat experiments. The directions accompanying the cultures distributed under the present plan may be summarized as follows:

For cultures that are to be increased by the planter, in one gallon of clean water, boiled and cooled, is dissolved a small quantity of sugar and the tablet which is supplied with the small bottle of culture. The liquid culture in this small bottle is poured into the gallon of solution and the mixture is allowed

to develop for twenty-four hours at a temperature of about 70° F., and is then ready for use.[a] The seed should be thoroughly moistened with this culture, without being soaked, and should then be spread out to dry in a clean, shady place. It is an advantage, though not an absolute necessity, to dry immediately by mixing with the moist seed a small quantity of dry, sifted earth. Planting should follow as soon as practicable, using the same methods as for untreated seed.

It is sometimes desirable to treat the soil direct instead of treating the seed. The solution is then mixed with enough dry soil (preferably from the field to be inoculated) so that it will just moisten the soil. This treated soil is again mixed thoroughly with a larger quantity of soil—say, half a wagonload for an acre. The inoculated soil is then distributed evenly over the prepared ground and should be harrowed in at once to avoid exposure to sunlight.

In special cases the amount of culture supplied is largely increased, and this is to be used immediately instead of waiting twenty-four hours for development. If the quantity of seed to be treated does not exceed 12 to 15 pounds the user has simply to open the bottle at once and pour the contents upon the seed. If more liquid is needed to moisten a larger quantity of seed, water up to 1 gallon may be added, reckoning 1 quart to a bushel of seed.

APPLICATIONS FOR CULTURES.

As cultivated soils in any one place are usually well supplied with the nodule-forming organisms adapted to inoculate the legumes that have been grown successfully for many years in that region, very little benefit will be obtained from further inoculation. To guard against useless experiments and to make those carried out of value for future guidance, the applicant for inoculating material is required to fill out a blank form which asks for information in regard to the legume to be treated, date of planting, soil conditions, etc.

On the reverse of the application form a circular letter gives briefly the plan of the distribution. Attention is called to the fact that the bacteria are beneficial only in connection with legumes, such as the various clovers (including alfalfa), vetches, peas, and beans, and are not applicable to other farm or garden crops.

REPORTS OF RESULTS.

It is expected that each one who secures a culture for inoculating legumes will follow the directions carefully and report the results, whether a success or a failure, to the Bureau of Plant Industry. Blanks for this purpose are furnished at the proper time. The main facts desired for this report are quantity of seed (or area) planted

[a] One gallon will treat at least three or four bushels of seed.

and date of planting; whether the culture was applied to the seed or soil; how the land was fertilized; whether it was new land, an old field, or garden soil; the kind of crop previously grown; and whether the culture when applied was clear, faintly clouded, milky, or frothy.

As to results, the roots should be examined to determine whether the nodules are present or absent and should be compared, if possible, with plants grown on ground not inoculated. In making this examination care should be taken in *digging* the plants not to detach the small root hairs. Plants simply pulled from the ground will usually be stripped of nodules along with the broken-off rootlets. Even with careful digging in compact soil it is necessary to examine the clumps of soil about the roots as well as the roots themselves. Any unusual conditions which appear to have affected the results of the experiment should be mentioned especially, together with information as to the general appearance and yield of the inoculated crop compared with the uninoculated portion or with previous experience with the same legume.

THE EFFECT OF SOIL CONDITIONS UPON LEGUME BACTERIA.

In the investigation of the results of inoculation the wide range of soils for which cultures have been furnished has brought out the complexity of the subject and developed many special problems. The constitution or character of the soil itself has been found to have an effect upon the growth of nodule bacteria, as well as upon the formation of nodules.[a] Some soils have a chemical composition distinctly unfavorable to the development of the introduced bacteria; other soils are so compact or retentive of moisture as to exclude air and thus be unfavorable to the growth of the bacteria and to nodule formation.

A study was made of the reports received from experimenters who used cultures for inoculating legumes to correlate, if possible, type and condition of soil, treatment, legume species, etc., for those showing favorable results and those showing unfavorable results. Two representative and widely grown legume crops were studied in this way—alfalfa and red clover. The only selection made in the reports chosen for this study was in taking all those received during the two calendar months of November and December, 1906. These were classified (as illustrated in the reports quoted on pages 15 to 19) into "successes" and "failures." The third class, of "doubtful" character, is not included in this statistical study. Success, as here used, means an observed increase in nodule formation showing benefit to the crop, while a fail-

[a] For a discussion of this, see Bulletin 100, Part VIII, of the Bureau of Plant Industry, U. S. Department of Agriculture.

ure is scored when attempted inoculation failed to produce nodules or produced so few as to be of no advantage to the plant. When natural inoculation proved abundant the experiment was set aside as inconclusive, as were also crop failures reported as due to poor seed, decidedly adverse season, and other factors clearly apart from the influence of inoculation. The reports, about one thousand in all, have been carefully studied, and the influence of the various factors upon nodule formation is expressed in terms of percentage in the following table:

TABLE I.—*Percentages of successful and unsuccessful inoculations under different soil conditions during November and December, 1906.*

Conditions of experiment.	Alfalfa.		Red clover.	
	Successes.	Failures.	Successes.	Failures.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
On new ground	81	19	95	5
On sand or sandy loam	75	25	87	13
On loam	70	30	88	12
On clay or clayey loam	65	35	92	8
On fallow or sod turned under	69	31	91	9
On old cultivated field soil	64	36	90	10
Crop new to the region	61	39	92	8

An examination of the data here shown does not warrant general conclusions of a positive character. Apparently none of the physical conditions reviewed are of great importance in determining the success or failure of inoculation. For the present, therefore, we must assume that such differences as exist in these particular cases, making one soil more favorable for inoculation than another, are, in part at least, biological, requiring more detailed investigation and experiment.

It is doubtless true that the cultures themselves have not always been in the most effective state at the time of use. With the safeguards observed at each point in their preparation and distribution, however, the cultures as they go from the laboratory are in a high state of efficiency. To secure the desired results they must of course be handled according to directions.

THE EFFECT OF INOCULATION UPON THE COMPOSITION OF THE CROP.

In some cases where there has been apparent failure to improve the legume crop, further examination may show a decided gain from inoculation. Even where the lack of nodule formation does not seem to hinder a healthy development of the plants careful comparisons from analyses have shown the greater protein content of those well supplied with nodules. The amount of nitrogen contained in a soy

bean crop [a] was found in one case to be 113.55 pounds to the acre for the inoculated plants and 75.98 pounds to the acre for those not inoculated, yet the appearance in the fields was the same. With cowpeas, inoculated and uninoculated, the nitrogen was found to be 139.21 pounds to the acre for the former and 118.45 pounds for the latter. In each case, therefore, the inoculated crop, although apparently not improved, was in reality much more valuable for feeding or for green manure than the uninoculated crop.

In addition, it should be noted that with the inoculated plants the gain of nitrogen came largely from the air, while the plants lacking nodules drew upon the combined nitrogen of the soil. When the gain in nitrogen from inoculation is accompanied by largely increased plant growth the beneficial effect of nodule formation is, of course, most pronounced. Some chemical analyses [b] of Canadian field peas, inoculated and uninoculated, serve to show in a striking manner the comparatively rich growth of the inoculated peas. The plants bearing nodules had a nitrogen content of 2.29 grams per 100 of dry substance; the plants without nodules grown in the same soil had 1.60 grams per 100 of dry substance. The average dry weight of inoculated and uninoculated plants was 11.2 and 2.3 grams, respectively. It is evident, therefore, that the inoculated plants supplied more than seven times the amount of nitrogen furnished by those not inoculated, viz, 0.255 gram to the plant, as compared with 0.035 gram to the plant.

Similar results were obtained with wild hemp plants (*Sesbania macrocarpa*), inoculated and uninoculated.[c] Analyses [d] of the nodules themselves and of the roots from which the nodules were removed show that, though the noduled plants made a decided gain in nitrogen in both roots and tops, by far the highest percentage of nitrogen was found in the nodules themselves. The following table shows these figures in detail:

TABLE II.—*Occurrence of nitrogen in inoculated and uninoculated plants of the wild hemp.*

[Grams of nitrogen per 100 grams of dry substance.]

1. Roots, stripped of nodules	1.50
2. Nodules (from No. 1)	6.40
3. Tops (from No. 1)	2.09
4. Whole plants (inoculated, having numerous nodules)	3.01
5. Whole plants (not inoculated, no nodules)	1.71

[a] Grown at Agricultural College, Mich. For description, see Bulletin 224 of the Michigan Station.

[b] Analyses made by the Bureau of Chemistry, U. S. Department of Agriculture.

[c] Experiment carried on by Mr. David Fairchild, in charge of Seed and Plant Introduction for the Bureau of Plant Industry.

[d] Analyses made by the Bureau of Chemistry.

In view of the generally recognized importance of nitrogen to the growth of plants[a] the significance of the foregoing facts needs little emphasis. A difference between abundant nodule formation and the absence of nodules, which may affect the value of a legume crop in the ratio shown, can not fail to command attention when its bearing on successful farming is once realized. It is not enough merely to count yields in pounds or tons. The composition of crops for feed or green manure becomes in the light of these investigations a factor of importance.

GREEN MANURING AND INOCULATION.

Generally speaking, the experience of scientific farmers and the tests of agricultural experiment stations agree in ascribing an unusual benefit to succeeding crops from green manuring with leguminous crops, and this is clearly due in considerable degree to the nitrogen fixed by the root nodules and not to the length of the root system or other peculiarities of leguminous plants. Unfortunately, investigators have not given sufficient attention to the relative abundance or scarcity of nodules when experimenting with different leguminous crops for green manures. From the preceding data it is evident that legumes reach their maximum value as green manures only when abundantly supplied with nodules.

CONFUSION OF NEMATODE GALLS WITH NODULES.

Nematode galls, or root knots, are often mistaken for nodules, which they resemble in appearance. The nematode gall is extremely injurious, and in regions where it has been known to exist it is unwise to plant crops favorable to the development of the pest. Nearly all of the legumes should be avoided in such cases. This is important not only because the legumes susceptible to nematode attack are themselves injured, but chiefly because they furnish conditions favorable to the rapid development and multiplication of the nematode worms, and these may become a serious menace to succeeding crops or to orchard stock, which under ordinary conditions they would scarcely injure. There are, however, some resistant varieties[b] upon which the nematode worm can not develop, and in infested regions these resistant varieties should be used exclusively. If a leguminous crop with its roots covered with what are apparently nodules makes a

[a] See Bulletin 247 of the New York (Ithaca) Agricultural Experiment Station.

[b] The most important and generally useful resistant variety is the Iron cowpea (*Vigna sinensis*). In the Southern States the velvet bean (*Mucuna utilis*) and Florida beggarweed (*Meibomia mollis*) are valuable.

sickly growth, or if there is doubt as to whether a legume is inoculated or infested with nematodes, samples for examination should be forwarded to the Bureau of Plant Industry of the Department of Agriculture.

WHEN INOCULATION IS DESIRABLE.

Inoculation is desirable—

(1) If the soil has not previously borne leguminous crops.

(2) If legumes previously grown on the same land were devoid of nodules.

(3) If the legume to be sown belongs to a species not closely related to one previously grown on the same soil.

(4) If the soil produces a weak growth of legumes, even though their roots show some nodules.

It is significant of the relative value of pure culture inoculation that a high percentage of beneficial results is being obtained, not only where legumes new to the region are being tried, but where the ordinary legumes used in rotation have been inoculated, a phenomenon which is undoubtedly due to the increased virility of the nodule-forming bacteria resulting from the proper development of the pure cultures in the laboratory. It is also true that the crops following the inoculated legumes have in many cases shown gains not evident in the legume crop. The practice of inoculating is therefore justified where legumes are naturally inoculated but do not seem to reach their full vigor nor to give the best results as green manures.

WHEN INOCULATION IS USELESS.

Inoculation is of no value—

(1) If the legumes usually grown are producing average yields and the roots show nodules in abundance.

(2) If the soil is in such condition as to prevent the normal growth of the bacteria or of the leguminous plants.

(3) If the directions for handling the cultures are not studied carefully and followed intelligently.

(4) If the soil is acid and in need of lime. Liming to correct acidity is as important for the proper activity of the bacteria as for the growth of the plants.

(5) If the soil needs fertilizers, such as potash, phosphoric acid, or lime. The activity of the nodule bacteria in securing nitrogen from the air and rendering it available to the legumes will not take the place of such fertilizing elements as potash and phosphorus.

It must be remembered that inoculation will not overcome results due to bad seed, improper preparation and cultivation of the ground, and decidedly adverse conditions of weather or climate. Before

attempting to inoculate a new crop the farmer should first inform himself thoroughly concerning the proper handling of the crop itself; otherwise failure is almost certain. As an illustration, sowing alfalfa on hastily prepared land, on land foul with weeds, and on acid soils or soils underlaid with hardpan, is contrary to accepted practice.

Free publications covering the essential points in growing all common legumes may be obtained from the State experiment stations and from the United States Department of Agriculture.

DANGER IN INOCULATION BY SOIL TRANSFER.

Very satisfactory inoculations have been obtained by transferring soil from old fields where legumes have been grown, but there are dangers incident to such soil transfer which should be noted.

The source of supply should be very definitely known, and in no case should soil be used from fields which have previously borne any crops affected with a fungous disease, a bacterial disease, or with nematodes. Numerous animal and plant parasites live in the soil for years and are established in so many localities that it is manifestly unwise to ship soil indiscriminately from one portion of the country to another.

Of scarcely less importance is the danger of disseminating noxious weeds and insect pests through this plan of inoculating by means of natural soils. Even though weeds may not have been serious in the first field, the great number of dormant seeds requiring but a slight change in surroundings to produce germination is always a menace.

If soil [a] is to be used, however, whether obtained from near-by fields or shipped long distances, the evidence should be clear that the soil is free from the objections mentioned above.

RESULTS OF COOPERATIVE FIELD TESTS.

The results of cooperative experiments with planters throughout the United States, begun in the spring of 1906 and reported upon during the autumn of that year, are presented here in tabular form. These reports are divided into three natural classes: Successes, doubtful results, and failures. To explain further the plan followed in this tabulation, quotations from representative reports under each class are given.

An examination of these sample reports will show that the successes credited to the culture have been so recorded only when a clear gain was shown to be due to inoculation. A less strict interpretation

[a] The quantity of soil from a thoroughly inoculated field regarded as sufficient for inoculating an acre of land for alfalfa, for instance, is variously placed at 200 to 500 pounds.

of the doubtful reports would place many of them in the column of successes, and undoubtedly many classed as failures to secure inoculation would prove upon adequate investigation to have been failures from causes other than deficient nodule formation.

TABLE III.—*Results of experiments with crops sown in connection with cultures of nitrogen-gathering bacteria in the spring of 1906.*[a]

Crop.	Successes.	Doubtful results.	Failures.	Total.
Alfalfa	403	657	182	1,242
Red clover	498	544	66	1,108
Garden pea	236	209	54	499
Garden bean	217	224	74	515
Cowpea	247	203	53	503
Canadian field pea	44	27	10	81
Vetch	16	19	4	39
Soy bean	23	40	23	86
Crimson clover	8	18	2	28
Sweet pea	22	29	8	59
Velvet bean	10	14	2	26
Alsike	33	24	3	60
White clover	2	2	0	4
Peanut	10	10	1	30
Bur clover	0	1	0	1
Beggar weed	0	1	3	4
Japan clover	1	0	0	1
Mung bean	0	1	0	1
Sainfoin	0	2	4	6
Sweet clover	0	3	0	3
Total	1,770	2,037	489	4,296

[a] Approximately 8,000 cultures were sent out. A little more than half of the recipients had reported results at the time this table was prepared. The general relation remains about the same, as additional reports have been tabulated since this table was prepared.

REPORTS OF INOCULATION EXPERIMENTS CLASSED AS SUCCESSES.

The following are examples of the experiments with nitrogen-gathering bacteria which have been classed as successes:

Alfalfa.—"Nodules are numerous on inoculated ground, while I fail to find any on uninoculated. The inoculated crop did fine, while the uninoculated was a failure, and always has been so far." (Ballagh, Nebr.)

Alfalfa.—"I find roots well filled with nodules. Alfalfa has a good dark-green color and grows thriftily, whereas in previous experiments it has kept small and yellow for the first three years. I cut three fair crops this year, although the rainfall was somewhat deficient." (Waupaca, Wis.)

Alfalfa.—"Quite a lot of nodules on inoculated plants and a very good stand; looks fine. Strip 30 feet wide and 400 feet long not inoculated has very poor stand and very few nodules." (Cleveland, Ohio.)

Red clover.—"The inoculated crop is of a strong and thrifty growth. All the seed that I sowed that was not inoculated died in forty to sixty days after planting, as did every clover field in this vicinity. There was a marked difference in the inoculated and uninoculated from the start; the inoculated seemed a better color and did not die out from the dry weather as the other did." (Paris, Mo.)

Red clover.—"By count I find from two to four times the number of nodules on inoculated area. I inoculated 20 acres; used commercial fertilizer on an

adjoining 20 acres, and on a third 20 acres nothing was used. One week ago on the inoculated area was to be seen clover of a much darker color and of twice the growth found on fertilized area. The results were highly satisfactory in every respect." (Lima, Ohio.)

Red clover.—"Roots covered with nodules. Clover on adjoining land, but better land, very poor. Inoculation certainly did increase the nodules and, of course, improved the crop. Clover sown last spring in this vicinity is poor, but mine sown upon high sand hills is all that I can ask: it exceeds my expectations. I am convinced that it is useless to sow clover on this ground without inoculation." (New London, Wis.)

Cowpea.—"The growth of nodules was fully 200 per cent better on the inoculated than on a small portion that was not inoculated. The increase of peas over the uninoculated was fully three to one. The increase of hay I did not take into close consideration, but on a fair estimate, I think, about 2½ tons an acre in favor of inoculated." (Buttonwood, Pa.)

Cowpea.—"There was a good supply of nodules on the inoculated plot, one plant having a good handful of large size at harvesting time. There were no nodules on three plots of the same size that were not inoculated. The uninoculated plot (Whippoorwill) yielded 6½ pounds grain; the inoculated plot (Whippoorwill) 9 pounds grain." (Pataskala, Ohio.)

Cowpea.—"Planted one-half acre in same field, using no culture; both had 500 pounds of same fertilizer per acre. Compared with roots where culture was used, found less nodules and turned down scant growth of pea vines to sow scarlet clover and rye. Where culture was used, found large number of nodules and rank growth of vines which remained green until peas matured and yielded 20 bushels per acre. Land now seeded to rye and scarlet clover, which is looking fine." (Withans, Va.)

Cowpea followed by oats.—"On a part of the ground on which the treated cowpeas had been grown I planted oats. They turned out 50 bushels to the acre, and on ground where the untreated cowpeas had grown they turned out only 25 to 30 bushels to the acre, no other fertilizer being applied to either piece of ground. Fields just adjoining mine have yielded only 25 bushels an acre." (Hammond, La.)

Cowpea followed by oats.—"I made up with supplies sent me from the Department 100 gallons of liquid culture, which was distributed among 20 farmers in this vicinity. Those who planted peas for forage have gathered twice the quantity of pea-vine hay from the ground in which the inoculated seed were sown. I repeated last year's experiment in following the peas, after the hay had been cut off, with oats in drills. So far as the eye can judge, the improvement in the oat crop is proportionally as great as that in the crop of pea vines." Others in this same group of cooperators reported as follows: "Cowpeas are practically unknown here (a large body of land in a bend of the Coosa River) and when sown last season without inoculation no nodules were formed. The bacteria secured largely increased the yield; 3 tons of hay from an acre of inoculated seed, one-half ton from uninoculated seed; made twice as many peas on land inoculated as on land not inoculated. Season too wet to gather peas." (Rome, Ga.)

Cowpea followed by corn.—"Where cowpeas were grown last year we have corn this year. The field is a 4-acre lot and includes sandy gravel as well as good rich loam. Over the entire portion where the cowpeas were grown with the culture the corn has a rich black color; on the area where no culture was used there is a distinct difference, the corn being smaller and not of such dark

color. This is very distinct, even on the heavy loam. The growth of cowpeas was estimated at twice as much last year where the culture was used as where there was none. The cowpea crop was cut last year, but on account of continual rains was left on the ground and plowed under." [a] (Vineland, N. J.)

Bean.—"Nonculture beans grew slowly, were light green (though not unhealthy), and had slender stem and sharper pointed, more delicate-looking leaf. Culture beans grew rapidly, were stout and deep green, and the leaves were thicker and blunter pointed. Nonculture beans bore ordinarily well, and after one bearing rusted and dried up. Culture beans were loaded, kept putting forth blossoms, and bore until frost killed them in October. On the roots of the nonculture beans there were a few minute and hard-looking nodules, and the roots were small and weak. On the roots of the culture beans the nodules were plentiful and juicy; the roots were long and vigorous. On reading your account of seed raised in pure sand from inoculated seed, I thought I would try coal ashes, and planted three hills of two varieties in our last winter's ash heap, scooping out a hole, laying in the beans, and covering with mixed earth and ashes. They grew wonderfully and bore until frost, and at that time had a fourth crop of blossoms." (Woodfords, Me.)

Vetch.—"A strip 25 or 30 feet wide was sown without inoculation. That part inoculated showed roots full of fine nodules, while the plants uninoculated showed none at all. The growth in the part of the field that had received the inoculation was three or four times as great as in that part not so treated." (Irving, Mich.)

Vetch for citrus orchard.—"Vetch was tried three years ago and gives good results. Eighty per cent of our orchardists now plant legumes to plow under, and find it profitable. Inoculated vines about 20 per cent heavier than uninoculated on soil never having had a crop of legumes. Our soil is a heavy red clay adobe, formerly a desert, and devoid of humus." (Redlands, Cal.)

Garden pea.—"Planted inoculated and uninoculated side by side. Inoculated had many nodules and large ones; uninoculated few and small, and some plants none at all. Inoculated foliage dark green; uninoculated yellowish green. Stems longer and growth more vigorous on inoculated, yield about double that of the uninoculated." (Parkersburg, W. Va.)

Canadian field pea for citrus orchard.—"The pea vines plowed under furnished orange and lemon trees with plentiful nitrogen. Fruit trees were never so vigorous as now. Where we did not inoculate we got less vine and nodules, and fruit trees are not so fine." (Glendora, Cal.)

Canadian field pea.—"Nodules well developed. No nodules on an adjacent uninoculated crop which, excepting inoculation, received the same treatment. Peas and hay much increased (nearly doubled) over adjacent uninoculated crop." (Mount Pleasant, N. J.)

Canadian field pea.—"The cultures were applied to one ton of peas; the other half ton was planted without inoculation. The nodules on plants from the inoculated seed were larger and twice as numerous as from the uninoculated. The inoculated crop was much more robust and thrifty. The planting was done in a foothill orange orchard with steep gradients. The purpose of the planting was to prevent washing, as well as for fertilization. I planted the

[a] The yields from these two portions were reported later as follows: Corn following uninoculated cowpeas averaged 75 bushels an acre; corn following inoculated cowpeas averaged 105 bushels an acre. These figures are for corn on the ear.

inoculated seed in one direction and the uninoculated crossing it in open spaces at right angles. The result was a decided checkerboard, with inoculated seed producing a crop twice as vigorous and high as the other." (Glendora, Cal.)

Soy bean.—"Inoculation increased nodules. On part of ground I spread soil from a soy-bean field; on part I planted seed with inoculating cultures; part of the field had no soil or inoculated seed. Both inoculated seed and soil from a soy-bean field caused vigorous growth of nodules; no nodules on ground not treated. Inoculated crop was dark green in color; uninoculated light green. Where soil was fertile the growth was about equal, but where soil was poor the growth of the inoculated bean was more than double that of the uninoculated." (Cazenovia, N. Y.)

Peanut.—"I planted one gallon of seed not treated through the center of the lot, making 14 rows. They were very inferior, with nodules about 50 per cent in number and about one-half the size of those treated. I consider the gain for the inoculated crop at least 100 per cent." (Winterpock, Va.)

Sweet pea.—"About one-third of plot I did not inoculate. In this area I could not find a single nodule, though the roots of the inoculated portion were literally loaded with them. The whole plot was manured the same and had the same treatment all the season. The vines on the inoculated portion were more rank and would weigh three or four times as much apiece as those on the uninoculated portion. There were noticeably more and better blossoms from the inoculated plot." (Townsend Harbor, Mass.)

Crimson clover.—"Inoculated clover had five times the number of nodules as that not treated; in fact, they were perfect. Two acres uninoculated did not have as much clover as 10 square feet where treated. The appearance of inoculated field is fine—stalks large and healthy; stalks on uninoculated portion small and few." (Manheim, Pa.)

REPORTS OF INOCULATION EXPERIMENTS CLASSED AS "DOUBTFUL."

The following are examples of reports which have been placed in the doubtful class:

Alfalfa.—"There is a good amount of nodules on roots. No other field of uninoculated alfalfa here; so I can not compare. General appearance good." (Jefferson, Oreg.)

Alfalfa.—"Could see no difference between the inoculated and uninoculated; first cutting, considerable weeds; second cutting averaged 1 ton per acre good alfalfa." (Floyd, Tex.)

Alfalfa.—"I failed to secure a stand; the wind blew the ground so that the young plants were destroyed." (Hansford, Tex.)

Alfalfa.—"I am sorry to report alfalfa was an entire failure, I think on account of ground being too wet." (Canisteo, N. Y.)

Red clover.—"This field has never had a very good stand of clover and it does not seem much better this year. Examined plants from both parts of field and both seemed to have plenty of nodules; possibly more plants and more nodules on inoculated portion." (West Chester, Pa.)

Red clover.—"Can not tell as to results. We had six weeks of dry weather, and my seed did not come up." (Mohemenco, Va.)

Garden pea.—"A very wet season made the crop a failure. No conclusions could be drawn." (Hanover, N. H.)

Garden pea.—"Very few nodules noticeable. No increase in crop; perhaps the culture had been mixed too long before being applied to seed—had stood about ten days." (Hanover, N. H.)

Cowpea.—"Roots full of nodules; peas grew rank whether inoculated or not. The cowpea seems to grow here so well that I do not think artificial inoculation any benefit when the season is wet and warm, as it was this year." (Millersville, Md.)

Cowpea.—"I could not tell much difference between inoculated and uninoculated. Owing to excessive rain, the peas were almost drowned out, and it was not a fair test." (Greensboro, N. C.)

Cowpea.—"I can not tell very much difference in quantity of nodules on inoculated and uninoculated seed; if there was any difference, it was in favor of the treated seed. The appearance of the treated seed is darker than untreated." (Valle Crucis, N. C.)

REPORTS OF INOCULATION EXPERIMENTS CLASSED AS FAILURES.

Examples of results classified as failures follow:

Alfalfa.—"The nodules were not present at any time. The plants grew nicely for a time, then died, as they did formerly on an adjoining plot of land. No crop of alfalfa ever matured on this or any adjoining lands." (Rome, Tenn.)

Red clover.—"Could not find any nodules on either inoculated or uninoculated crop. It is the first clover ever sown on that field; it has been in wheat and corn for thirty years. Got a good stand, but it is mostly small, except where stable manure was spread." (McMinnville, Tenn.)

Cowpea.—"I examined peas on all parts of my place and found but few nodules. I could find no difference in the treated and untreated seed. I am inclined to think my inoculation was not right when I used it. My land appears to be without the proper bacteria; nodules are almost entirely lacking, and of course I can get but little results from my pea crop." (Moro, Ala.)

Soy bean.—"Plants were carefully dug, but had no sign of nodules, either treated or untreated. Culture may have been beyond the milky state but did not appear frothy. Good rank root system but no nodules." (Higganum, Conn.)

Garden bean.—"I examined the roots at different times and found only two nodules on the roots, and they were imperfect in appearance. There was no perceptible difference between inoculated and uninoculated." (Reedsville, W. Va.)

Garden pea.—"No nodules on either inoculated or uninoculated; no difference in growth. Extremely dry weather seemed to be the only cause for this being the poorest crop I have ever grown." (Ashland, Va.)

Vetch.—"Inoculation had no effect; total failure; no difference; soil, sandy loam, very poor and hungry." (Anamosa, Iowa.)

SUMMARY.

1. Abundant nodule formation improves the chemical composition as well as increases the quantity of a leguminous crop.

2. Leguminous crops with nodules are more valuable as green manure than leguminous crops lacking nodules.

3. Nematode galls or root-knots resemble nodules in appearance, but they are very injurious and care should be taken not to confuse the two growths.

4. It is wisest to depend upon pure cultures for inoculating purposes. If soil is to be used, however, great precautions should be taken in selecting and handling the soil to guard against the introduction of weeds or plant diseases.

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